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ANALYSIS OF PURSUIT TRACKING EYE MOVEMENTS IN PILOTS AND NONFLIERS

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Abstract

Pursuit tracking eye movements were recorded and analyzed from a group of Air Force pilots and a group of nonflying Air Force members. The tracking performance of the pilots was compared to the performance of the nonfliers. Subjects tracked a small spot of light moving sinusoidally in the horizontal plane at frequencies ranging from 0.2 to 1.0 Hz at a peak-to-peak amplitude of 40°. Maximum target velocities ranged from 25 to 126°/s. An adaptive nonlinear digital filter was used to separate the total tracking response (TTR) into smooth pursuit (SP) and saccadic (SA) components. Frequency domain analysis was used to relate the tracking components to the target movement. There were no statistically significant differences in tracking performance between the pilots and nonfliers. When tracking the 0.2 and 0.4 Hz targets, the TTR consisted principally of SP tracking with SA tracking representing less than 11% of the TTR. As the target velocity increased, the TTR remained adequate but the proportion of SP tracking decreased while the SA tracking increased. Over one-half of the TTR is contributed by the SA system when tracking the 1.0 Hz targets for both the pilot and nonpilot groups.

INTRODUCTION

Flying modern, high-performance aircraft requires superior sensory-motor skills. One of the more important skills is acquiring and tracking moving visual targets. Tracking while flying is complex, involving the *smooth pursuit* and *saccadic* eye movement systems as well as the *optokinetic* and *vestibulo-ocular* reflexes. We have been studying eye-tracking in a less complex setting with the head fixed and targets moving against a stationary background, thereby eliminating the influence of the vestibular and optokinetic systems. We recently reported a study of pursuit tracking using nonflying volunteers and selected neurological patients [9]. The task parameters chosen for this study permitted most of the "normals" to track with nearly perfect scores although several showed a clear performance deficit. This result suggested that pursuit tracking performance may be sensitive to slight differences in the sensory-motor skills required for flying. In order to test this hypothesis, we conducted a study to compare the tracking performance of a group of pilots to a nonflying normal group using a more challenging tracking task.

METHODS

Subjects: We tested 12 Air Force pilots and 11 nonflying Air Force members. Pilots ranged in age from 25 to 49, median age 36; nonfliers ranged in age from 26 to 46, median age 36. Participants were all active duty military personnel with no history of disease or injury that might affect tracking performance. All participants were briefed as to the purpose of the research and the testing procedures to be used. The voluntary, fully informed consent of the subjects used in this research was obtained as required by AFR 169-6.

Apparatus: Subjects were instructed to track a small spot of red (628 nm) light moving sinusoidally in the horizontal plane while the movement of each eye was recorded. The target was generated by a 1-mW, He-Ne laser. A General Scanning G-300DP scanner and a General Scanning CCX-650 controller provided the target motion. The target was projected onto a curved screen located 2 m in front of the subject. Target motion was sinusoidal, with a peak-to-peak amplitude of 40° and a frequency ranging from 0.2 to 1.0 Hz in increments of 0.2 Hz. Increasing target frequency corresponds to increasing levels of tracking difficulty. Target movement characteristics are given in Table I. Head stabilization was provided by a bite bar. Eye movements were recorded using a modified version of the infrared reflectance device previously described by Engelken, *et al.* [6]. A Compaq DeskPro 386/33 computer equipped with Analog Devices RTI-800-A (A/D) and RTI-802-8 (D/A) boards was used to generate driving signal for the scanner and digitize the eye-movement responses. The eye-movement signals were digitized to a resolution of 12 bits at a rate of 125 Hz. The eye-movement signals and the target position were stored in files on the hard disk for later analysis.

TABLE I. Target Movement Characteristics

Frequency (Hz)	Peak Movement (degrees)	Peak Velocity (deg/s)	Peak Acceleration (deg/s^2)
0.2	20	25.1	31.6
0.4	20	50.3	126
0.6	20	75.4	284
0.8	20	100.5	505
1.0	20	125.7	790

Testing Procedures: Tracking performance was evaluated at each of the 5 target movement frequencies listed in Table I. Subjects tracked 10 cycles of target movement at each frequency beginning at 0.2 Hz and progressing to 1.0 Hz with a 5-s pause between each of the 10-cycle epochs. The eye-movement recording system was calibrated before data collection by having the subjects fixate stationary targets at 5° intervals across the target movement range. A third-order polynomial was fit to the calibration data and used to linearize the recorder output.

Data Analysis: The eye-position signal represents the *total tracking response* (TTR) of the subject pursuing the target. The TTR consists of *smooth pursuit* (SP) and *saccadic* (SA) components. The SP component represents "quality" tracking; visual acuity remains high. The SA component represents the refixation eye movements that are needed to re-acquire the target when the SP system fails to provide adequate tracking. Visual acuity is suppressed during the refixation movements. A data analysis procedure was developed to determine the adequacy of the TTR and to quantify the SP and SA components. The TTR was separated into its SP and SA components using a nonlinear adaptive digital filter [7, 8]. A detailed description of the signal analysis is given by Engelken *et al.* [9]. The transfer function (gain and phase) of the TTR was calculated by considering the target signal as the system input and the eye-position signal as the system output. The SP component was quantified by computing gain, phase and asymmetry using target velocity as the system input and SP velocity as the system output. A parameter termed *tracking deficit* TD was calculated as,

$$\mathrm{TD} = \left\{1 - \frac{\text{SP Gain}}{\text{TTR Gain}}\right\} \times 100\%$$

where SP Gain and TTR Gain are results of the gain calculations described above. TD represents the difference between the gain of the TTR and the SP component. Increased TD indicates reduced SP tracking and increased SA tracking.

Tracking data were recorded and analyzed from each eye separately. The results were then statistically evaluated to determine if any significant left-eye, right-eye tracking differences were present. Then the pilot and nonpilot groups were tested to determine if pilots tracked significantly better than nonfliers. Finally, normative values were established.

RESULTS

There were no significant differences between left-eye and right-eye tracking and no differences between pilot and nonpilot tracking performance. In view of these findings, we averaged responses across subjects and determined the mean value and 95% confidence limits for future observations for TTR Gain, SP Gain, and TD. These results are presented in Tables II, III, and IV. Mean values are presented in Figure 1.

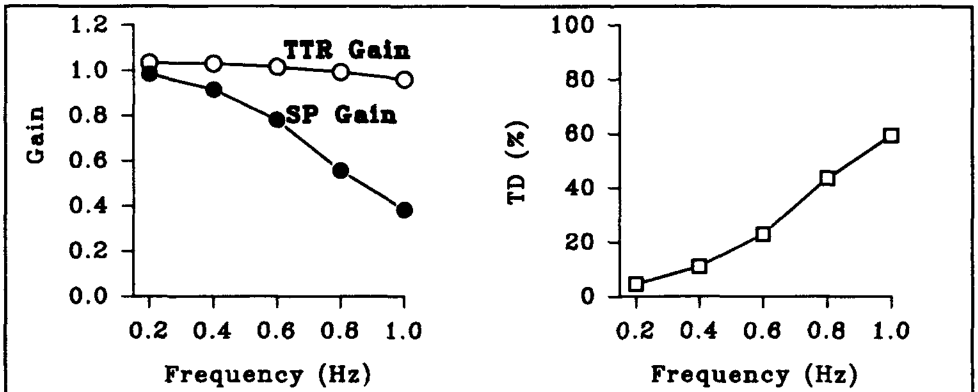

FIGURE 1. Mean TTR Gain, SP Gain, and TD as a function of frequency.

TABLE II. Total Tracking Response Gain
–Means and 95% Confidence Limits–

Frequency	Lower 95%	Mean	Upper 95%
0.2	0.976	1.034	1.091
0.4	0.956	1.031	1.106
0.6	0.922	1.015	1.108
0.8	0.872	0.993	1.113
1.0	0.792	0.961	1.130

TABLE III. Smooth Pursuit Gain
–Means and 95% Confidence Limits–

Frequency	Lower 95%	Mean	Upper 95%
0.2	0.900	0.986	1.072
0.4	0.770	0.917	1.064
0.6	0.528	0.781	1.034
0.8	0.214	0.557	0.900
1.0	0.045	0.382	0.719

DISCUSSION

Analysis of pursuit tracking performance has been used in the diagnosis of central nervous system disorders for many years [2, 3, 4, 5, 9]. In this study, we have been exploring the use of tracking performance as an indicator of sensory-motor skill. Our study involves pursuit tracking in a less complex environment than actual flying, but offers a significant challenge to the pursuit eye-tracking systems. As the frequency of the target motion (and target velocity) increases, the TTR shows little degradation but the tracking strategy shifts from a predominantly SP paradigm to a SA paradigm. Tracking deficit (TD) increases steadily as the target movement frequency increases (Fig. 1). The 95% confidence limits on TD expand as the target velocity increases, indicating increased variability in performance as task difficulty increases.

We could not find significant differences in the tracking performance between rated pilots and nonflying Air Force members in this small study. This result is not totally unexpected. Bahill determined that the latency and peak velocity of saccadic eye movements of baseball players were not different from nonathletic college students [1]. The mechanics of target tracking probably plays a secondary role in acquiring, identifying, and tracking a moving target in a realistic situation. Various cognitive factors conditioned by experience and practice are probably more important than the mechanics. Good eye-movement mechanics may be necessary, but perhaps not sufficient, for superior tracking performance in the complex sensory environment of the modern cockpit.

TABLE IV. Tracking Deficit (TD)
–Means and 95% Confidence Limits–

Frequency	–Lower 95%–	–Mean–	–Upper 95%–
0.2	0.000	4.569	12.02
0.4	0.000	10.96	25.92
0.6	0.000	22.91	48.73
0.8	8.244	43.60	78.95
1.0	22.64	59.54	96.44

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